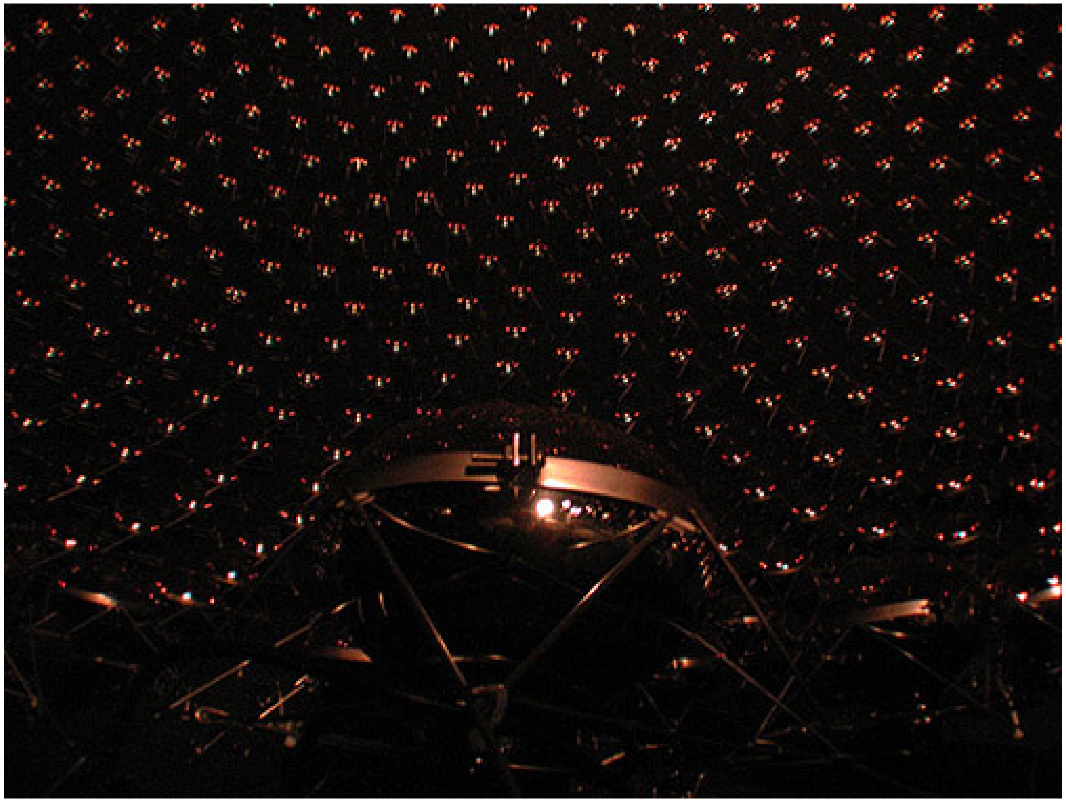
MiniBooNE

Michel Sorel (Columbia University)

FNAL Users' Meeting, June 2003



- Physics
- Overview of the Experiment
- First look at the data
- Understanding the data

MiniBooNE Timeline and Physics Potential

1997 2000 2003 now 2006 2009

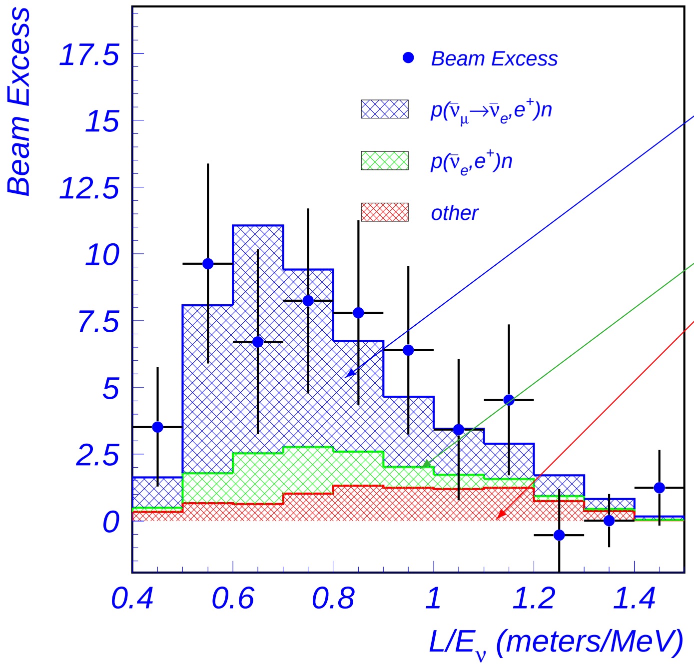
- Proposal
- Beamline and detector completed
- MiniBooNE is SN-live
- **First light from beam neutrinos**
- Measure $\nu_\mu \to \nu_{\not\mu}$
- Measure $\sigma(\nu_\mu)$ ratios
- Measure strange spin of the nucleon
- Results on exotic searches
- Measure absolute $\sigma(\nu_\mu)$
- **Measure** $\nu_\mu \to \nu_e$
- More $\nu/\bar{\nu}$ running?
- Build 2nd detector (BooNE)?

The MiniBooNE Collaboration

- Y. Liu, I. Stancu, **University of Alabama**
- S. Koutsoliotas, **Bucknell University**
- C. Green, **University of California, Riverside**
- E. Hawker, R. A. Johnson, J. L. Raaf, **University of Cincinnati**
- T. Hart, E. D. Zimmerman, **University of Colorado**
- L. Bugel, J. M. Conrad, J. Formaggio, J. M. Link, J. Monroe, M. H. Shaevitz, M. Sorel, G. P. Zeller, **Columbia University**
- D. Smith, **Embry Riddle Aeronautical University**
- L. Bartoszek, C. Bhat, S. J. Brice, B. C. Brown, D. A. Finley, B. T. Fleming, R. Ford, F. G. Garcia, P. Kasper, T. Kobilarcik. I. Kourbanis, A. Malensek, W. Marsh, P. Martin, F. Mills, C. Moore, P. Nienaber, E. Prebys, A. D. Russell, P. Spentzouris, R. Stefanski, T. Williams, **Fermi National Accelerator Laboratory**
- D. C. Cox, J. A. Green, H.-O. Meyer, R. Tayloe, **Indiana University**
- G. T. Garvey, W. C. Louis, G. McGregor, S. McKenney, G. B. Mills, E. Quealy, V. Sandberg, B. Sapp, R. Schirato, R. Van de Water, D. H. White, **Los Alamos National Laboratory**
- R. Imlay, W. Metcalf, M. Sung, M. O. Wascko, **Louisiana State University**
- J. Cao, Y. Liu, B. P. Roe, **University of Michigan**
- A. O. Bazarko, P. D. Meyers, R. Patterson, F. C. Shoemaker, H. Tanaka, **Princeton University**

- $\sim$ 60 scientists
- 13 institutions

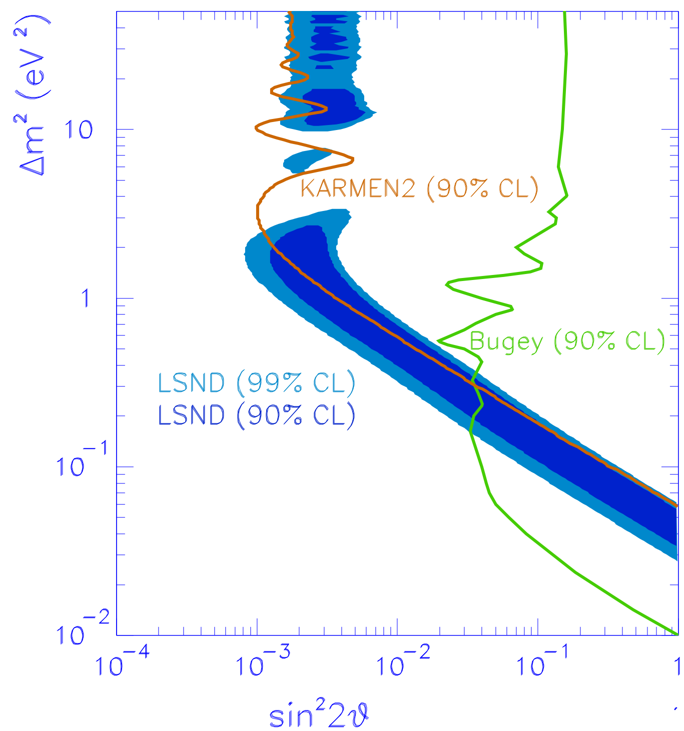
The LSND Result



Oscillation signal expectation

Backgrounds

- 4σ excess of $\bar{\nu}_e$ events in a $\bar{\nu}_\mu$ beam
- Evidence for $\bar{\nu}_\mu \longrightarrow \bar{\nu}_e$ oscillations



- Two-neutrino oscillations:

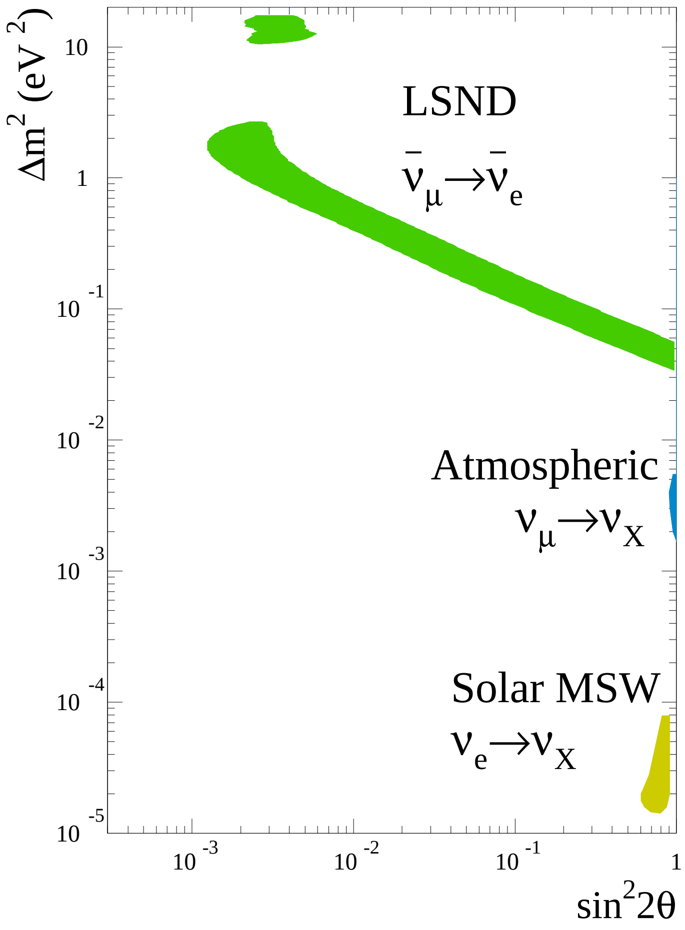
$$\begin{pmatrix} \nu_e \\ \nu_\mu \end{pmatrix} = \begin{pmatrix} \cos\vartheta & \sin\vartheta \\ -\sin\vartheta & \cos\vartheta \end{pmatrix} \begin{pmatrix} \nu_1 \\ \nu_2 \end{pmatrix}$$

$$\Delta m^2 = m_2^2 - m_1^2$$

- Oscillation probability:

$$P_{\bar{\nu}_\mu \to \bar{\nu}_e} = \sin^2 2\theta \sin^2(1.27 \Delta m^2 L/E)$$

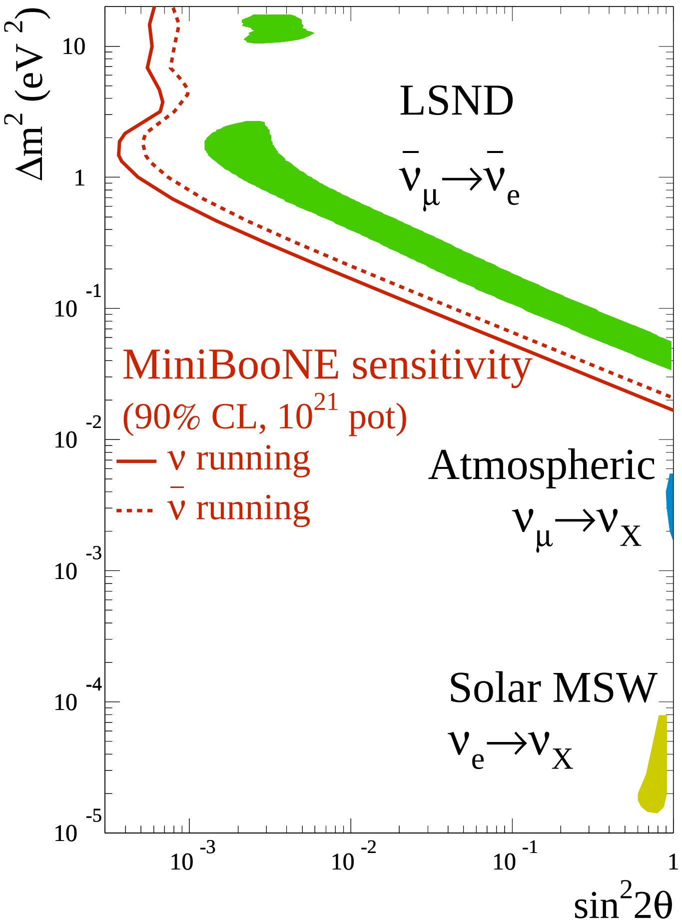
Beyond minimal extensions of the SM?



- Three distinct neutrino oscillation signals, with: $\Delta m^2_{sol} + \Delta m^2_{atm} \neq \Delta m^2_{LSND}$
- LEP: only three, light, weakly-interacting neutrinos
- Possible ways out...

  1. One experiment is not due to oscillations
  2. Active-to-sterile neutrino oscillations
  3. CPT violation

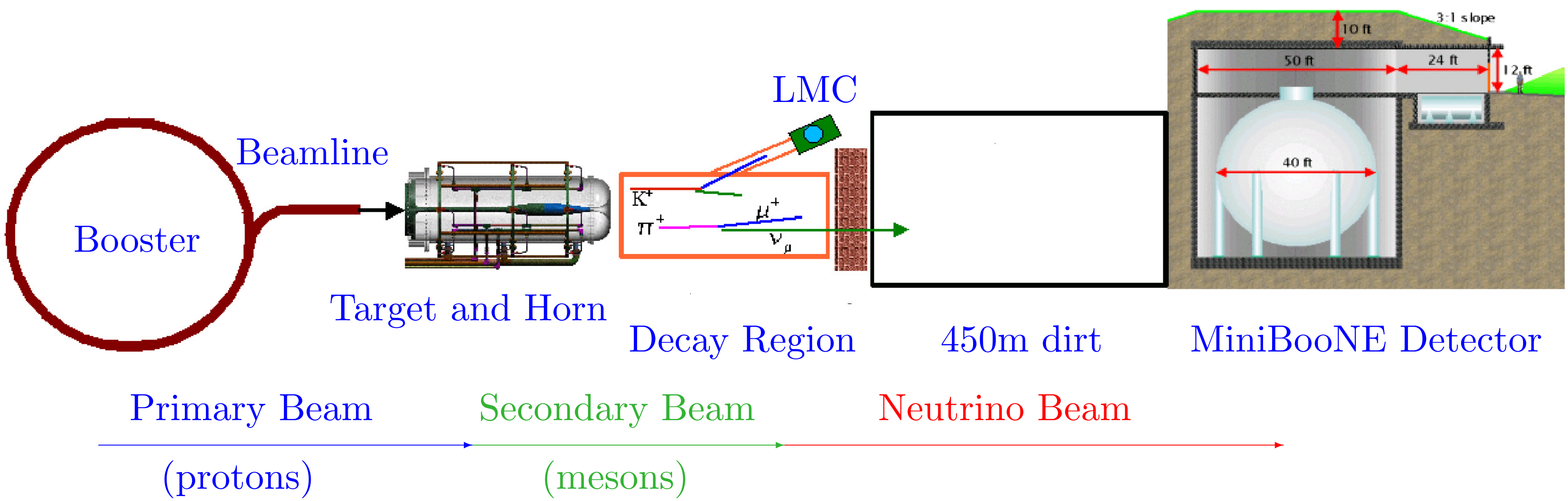
Beyond minimal extensions of the SM?



- Three distinct neutrino oscillation signals, with: $\Delta m^2_{sol} + \Delta m^2_{atm} \neq \Delta m^2_{LSND}$
- LEP: only three, light, weakly-interacting neutrinos
- Possible ways out. . .
  1. One experiment is not due to oscillations
  2. Active-to-sterile neutrino oscillations
  3. CPT violation
- MiniBooNE can address all these possibilities:

1. Check LSND with different systematics, higher statistics, similar L/E
2. $\nu_\mu \to \nu_e$ versus $\nu_\mu \to \nu_{\not\mu}$
3. ν versus $\bar{\nu}$ running mode

Booster Neutrino Beam

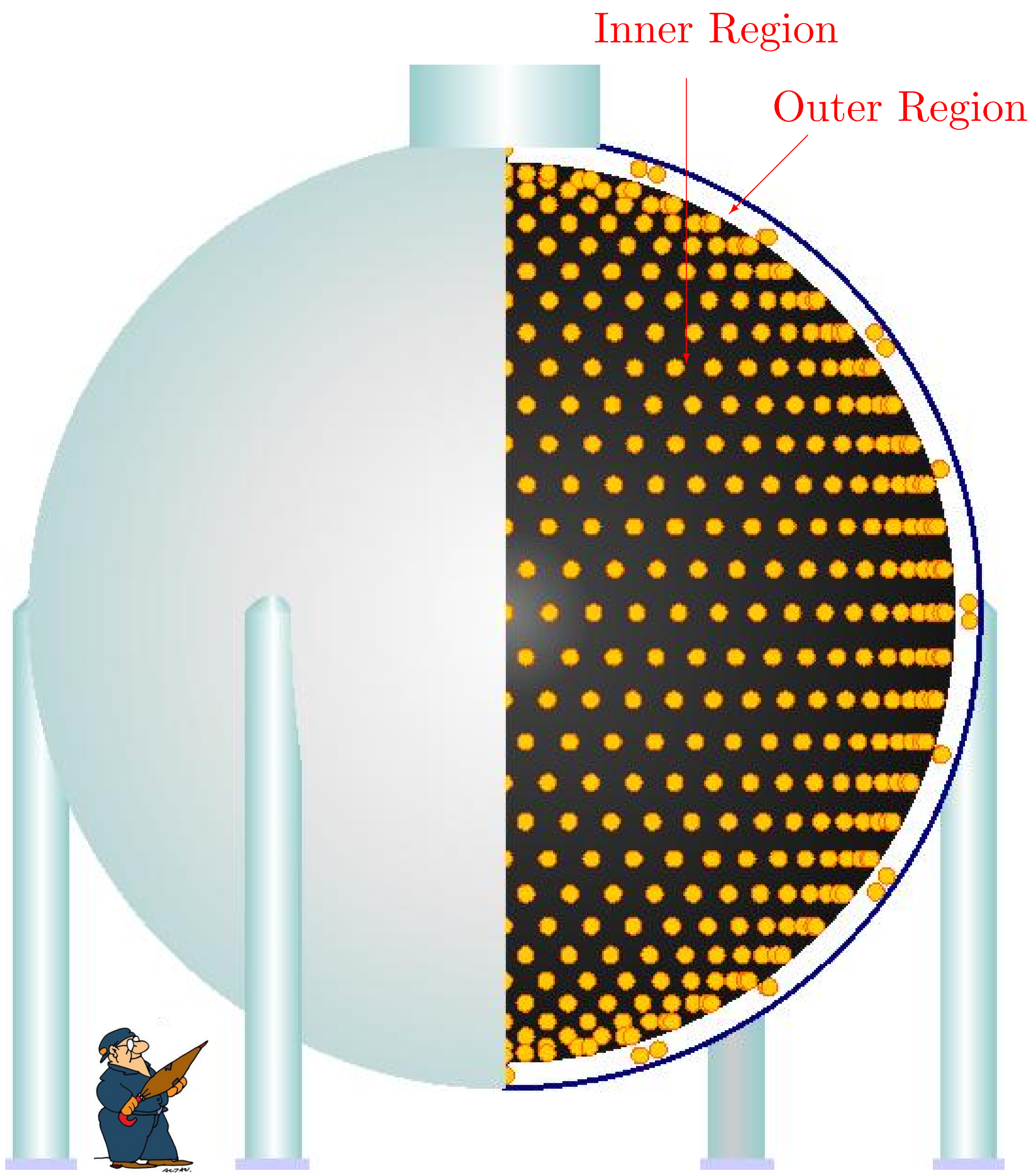


Primary Beam: 8 Gev protons from Booster, $8 \cdot 10^{-6}$ duty factor

Secondary Beam: mesons are produced from protons striking Be target, focused by horn, and monitored by "Little Muon Counters" (LMC)

Neutrino Beam: neutrinos from meson decay in 50m pipe, pass through 450m of dirt (and oscillate?) to reach MiniBooNE detector

MiniBooNE Detector

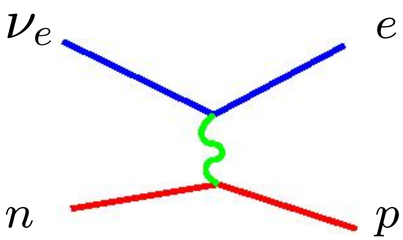
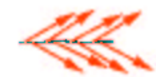
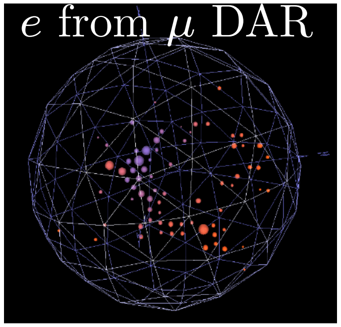
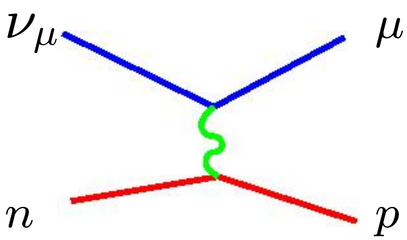
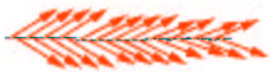
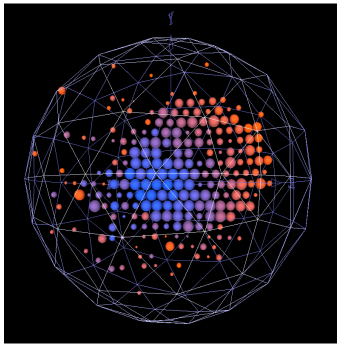
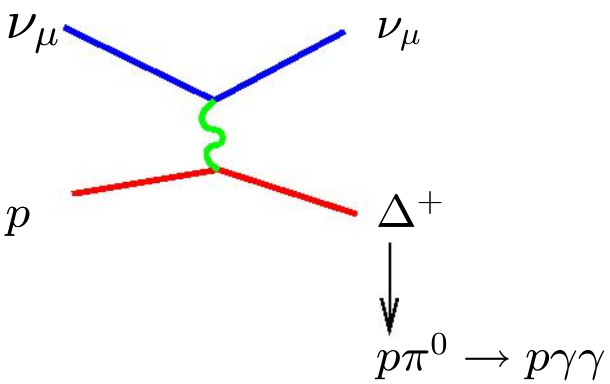
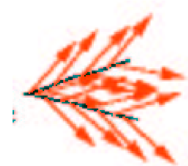
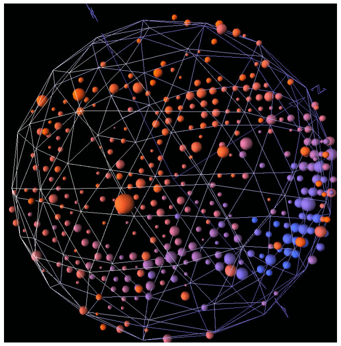


- 12m in diameter sphere filled with 800t of pure mineral oil
- Light tight inner region with 1280 8” PMTs (10% coverage)
- 240 PMTs in outer region (>99% veto efficiency)
- Neutrino interactions in oil produce:

1. Prompt, ring-distributed Cherenkov light
2. Delayed, isotropic scintillation light

Particle ID

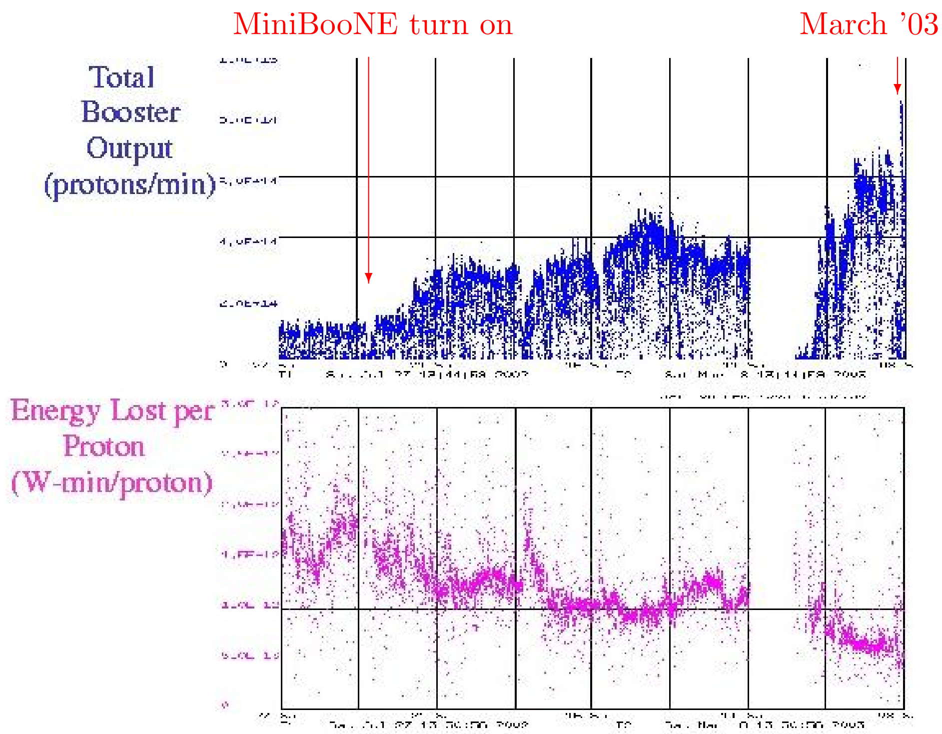
- $e/\mu/\pi^0$ separation:

	Correlated e's from μ DAR	Veto Activity	Track Extent	Hit Topology
	0	no		
	0 or 1	possible		
	0	no		

- Nuclear recoil: use scintillation/Cherenkov fraction

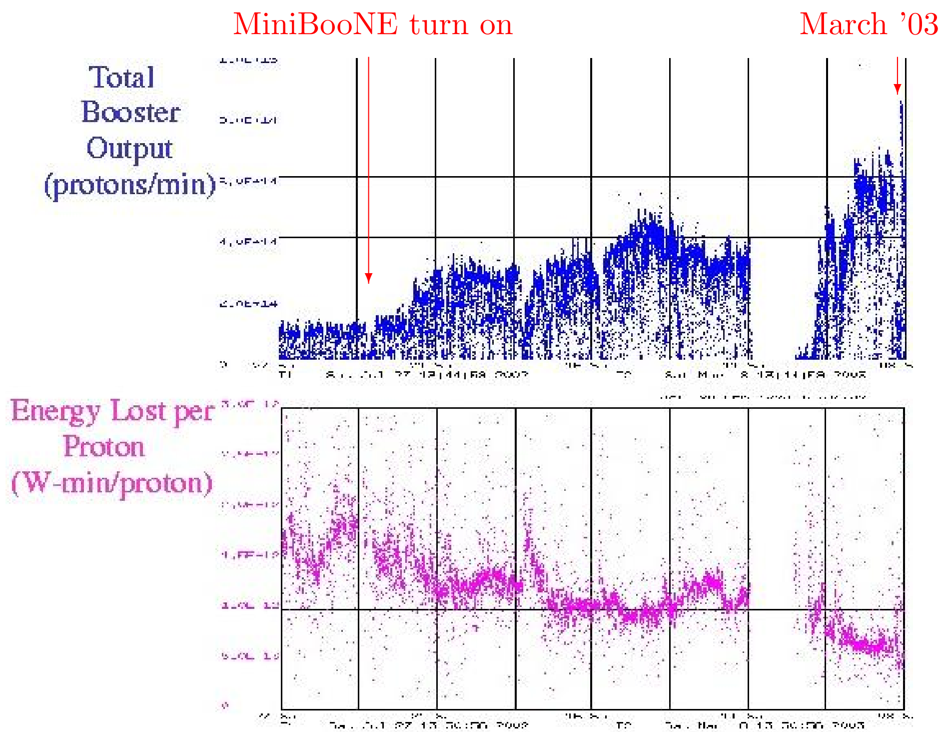
REAL DATA!

Booster Performance



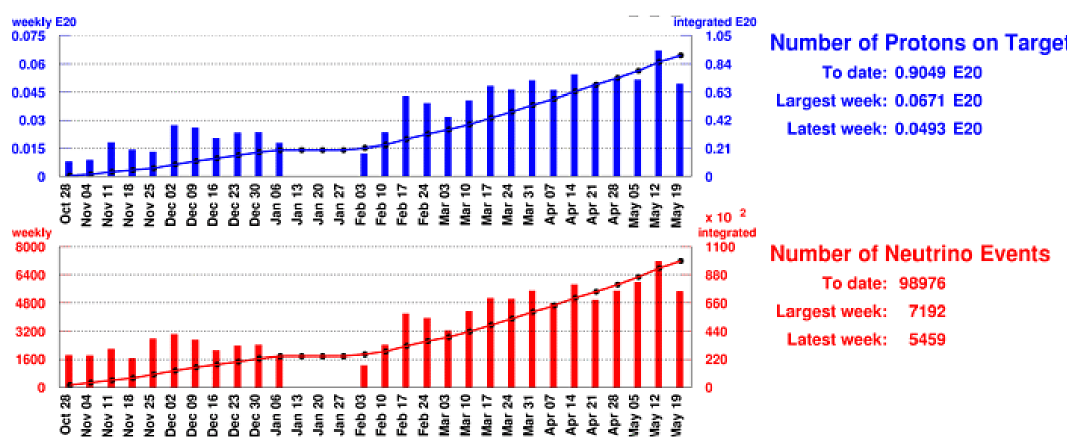
- Booster is working harder than ever!
- Steady increase of rate of delivered protons
- Currently factor of 2-3 below designed intensity. Designed intensity can be reached with planned Booster upgrades
- THANK YOU BEAMS DIVISION!
- Booster effort is already paying off. . .

Booster Performance



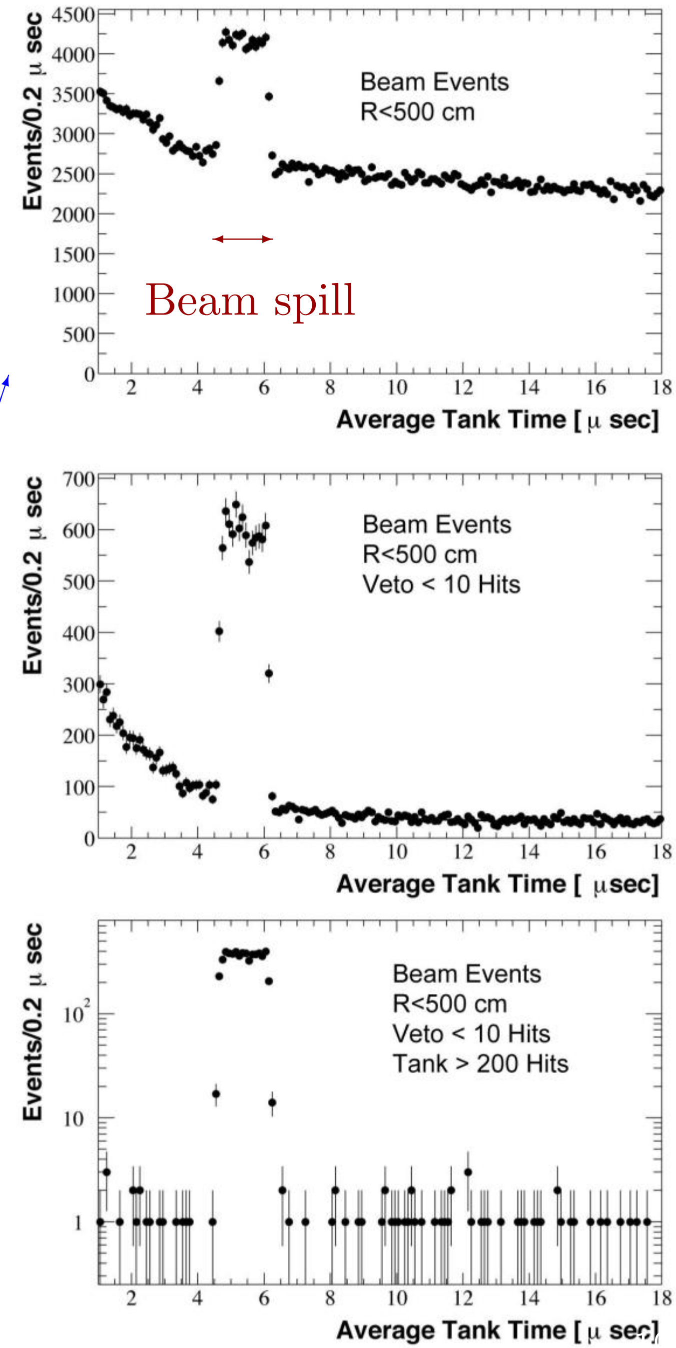
- Booster is working harder than ever!
- Steady increase of rate of delivered protons
- Currently factor of 2-3 below designed intensity. Designed intensity can be reached with planned Booster upgrades
- THANK YOU BEAMS DIVISION!
- Booster effort is already paying off...

- Currently at 10% of 10^{21} protons on target
- 100,000 ν_μ event candidates collected so far



Beam Event Timing

- Beam comes in spills at ∼3 Hz (we hope to bring this to 5Hz)
- Each spill: 82 bunches separated by 19ns $\Rightarrow 1.6\mu s$ spill
- Trigger on signal from Booster; readout for 19.2 μs
- No high level analysis needed to see neutrino events over background!
- A few very simple cuts are sufficient to reduce the beam unrelated background to $< 10^{-3}$
- We can even tell which RF bucket a neutrino comes from



Data Reconstruction

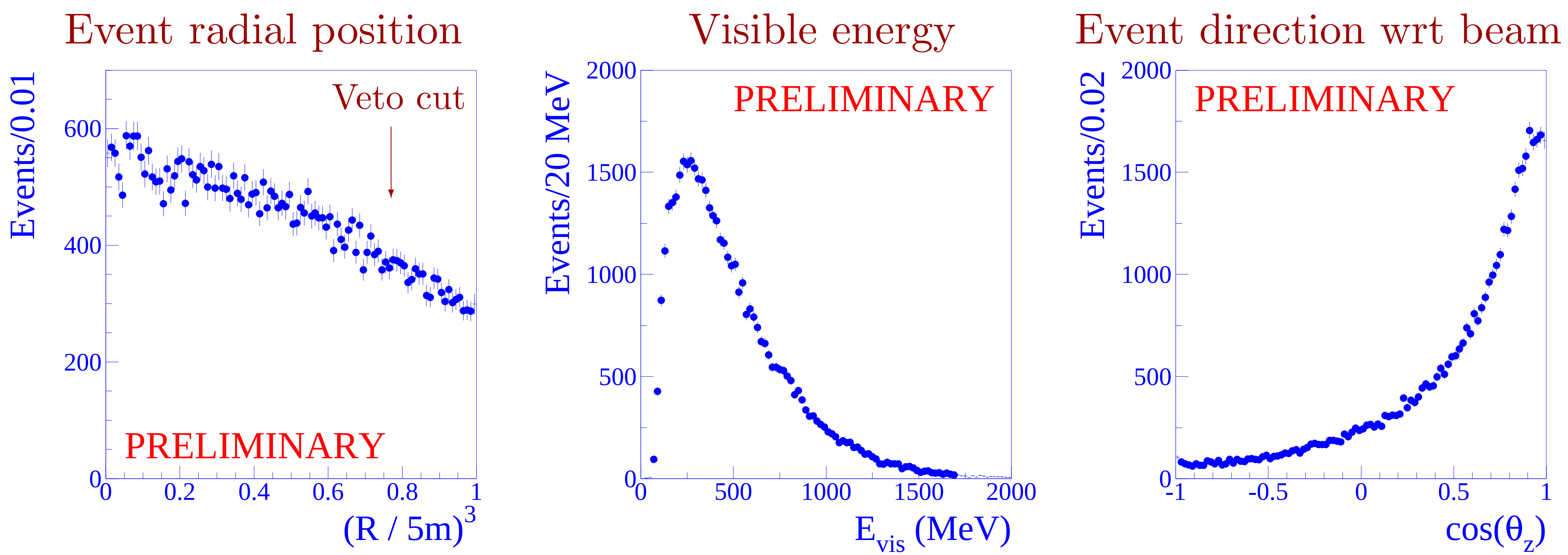
- Select events with no particle ID requirements:

  1. In time with beam
  2. Center of event track within a 5m radius
  3. Contained event (low veto activity)
  4. Visible energy greater than endpoint for electron from μ DAR

Data Reconstruction

- Select events with no particle ID requirements:

  1. In time with beam
  2. Center of event track within a 5m radius
  3. Contained event (low veto activity)
  4. Visible energy greater than endpoint for electron from μ DAR

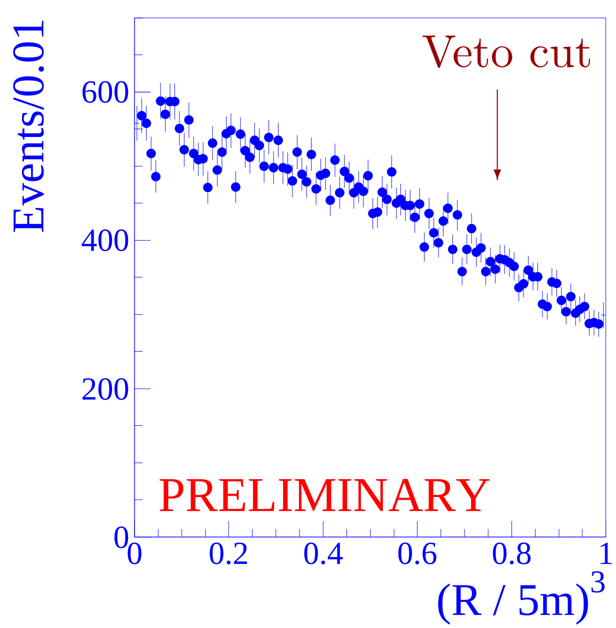


Data Reconstruction

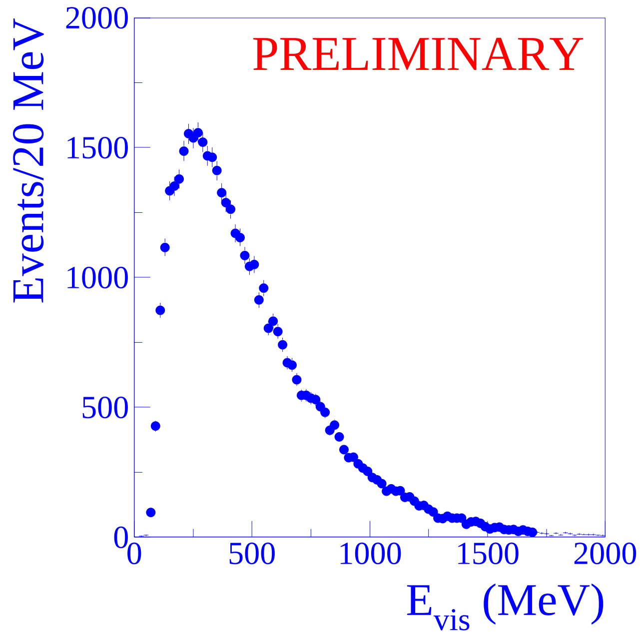
- Select events with no particle ID requirements:
  1. In time with beam
  2. Center of event track within a 5m radius
  3. Contained event (low veto activity)
  4. Visible energy greater than endpoint for electron from μ DAR

- Reconstruction works well
- In the process of assigning uncertainties to MC expectations
- Data/MC comparisons in the fall, with first physics results

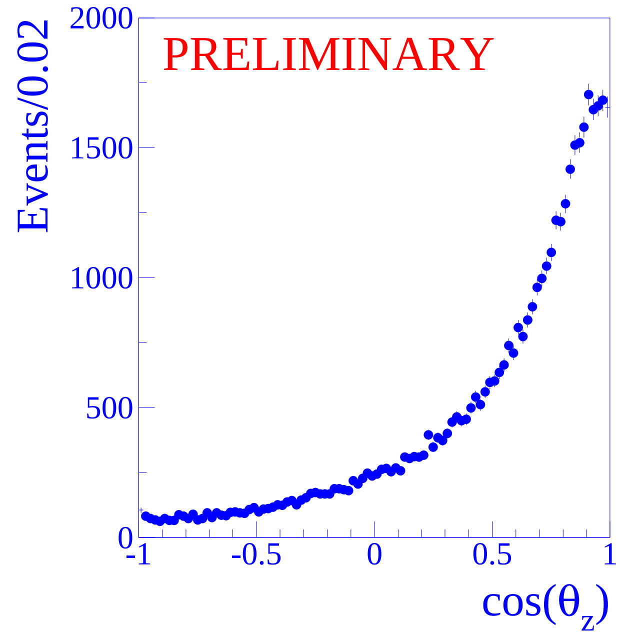
Event radial position



Visible energy



Event direction wrt beam

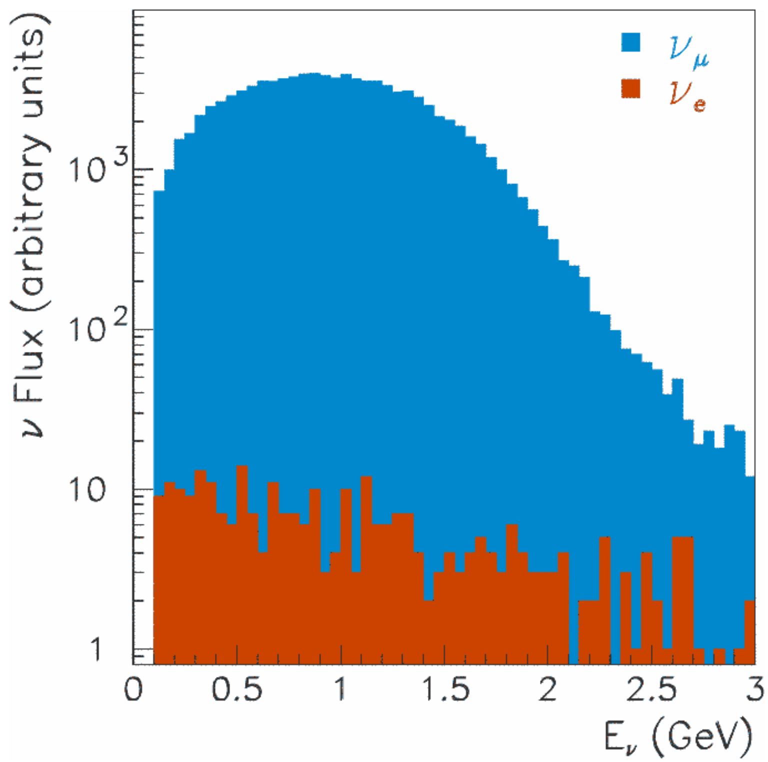


Understanding the neutrino fluxes

- Most neutrinos from: $\pi^+ \to \mu^+\nu_\mu$
- For $\nu_\mu \to \nu_e$ search, important background is intrinsic ν_e background in the beam:

$$K \to \pi e \nu_e, \qquad \pi^+ \to \mu^+\nu_\mu$$
$$\hookrightarrow \bar{\nu}_\mu e^+ \nu_e$$

- Flux uncertainty dominated by uncertainty on π, K production in p-Be interactions
- Constrain neutrino flux predictions with existing π production data, BNL E910, and CERN HARP

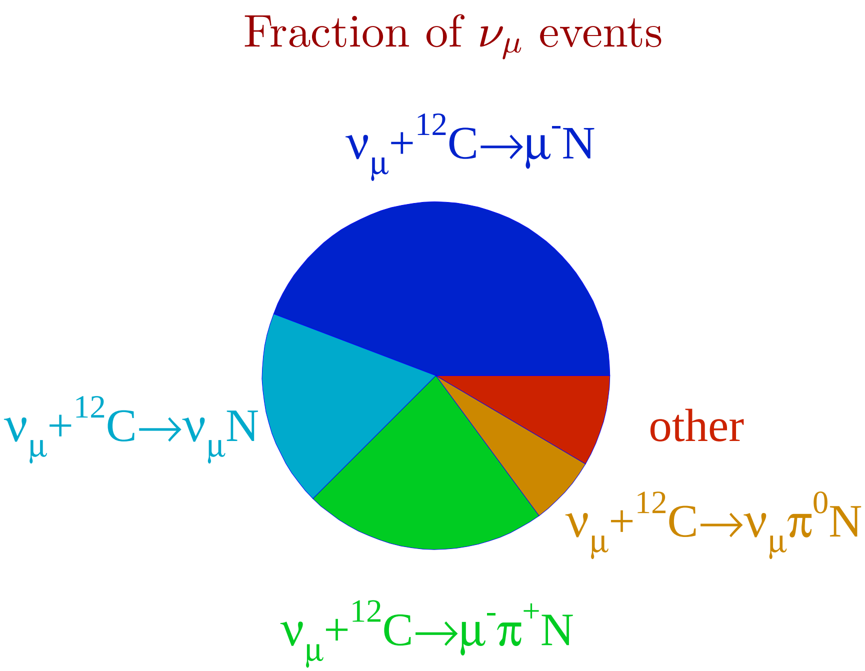


- Internal cross-checks:

1. ν_e from K^+ decays from high p_t muons in LMC (to be installed this summer)
2. ν_e from μ^+ decays ν_μ data and variable-length decay region

Understanding the neutrino cross-sections

- At $\sim$ 1GeV, dominant processes are neutrino-nucleon quasi-elastic scattering and resonant π production
- Low energy regime and nuclear effects complicate things
- Example: final state interactions impact kinematics/rates and observed final states

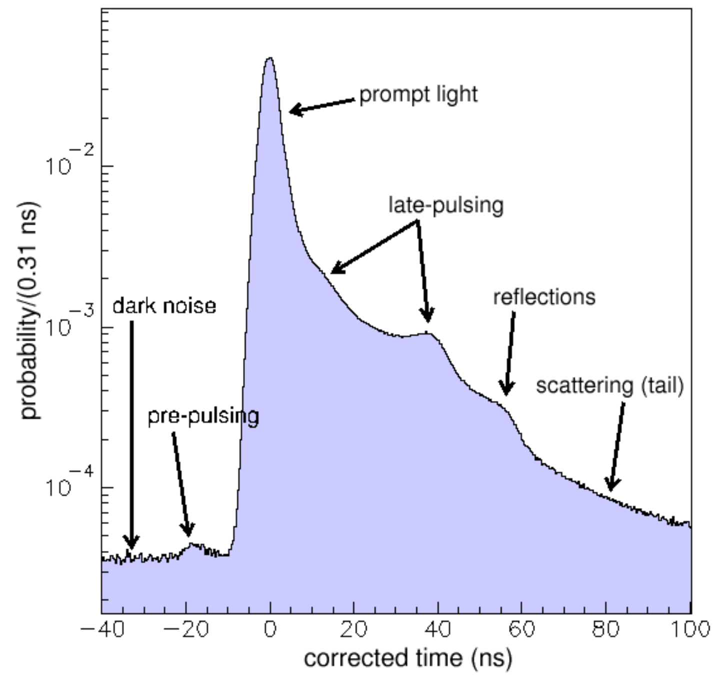


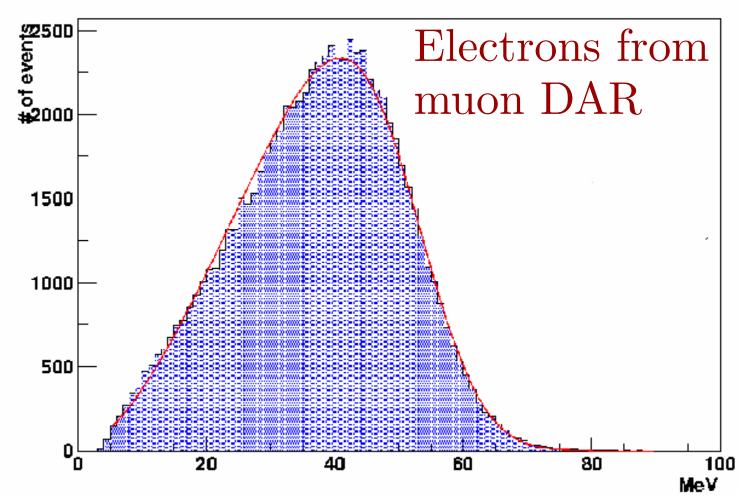
- MiniBooNE uses and develops the NUANCE ν cross-section generator $\Rightarrow$ world-wide collaboration within the neutrino physics community
- MiniBooNE will measure a variety of neutrino cross-sections
- Useful for other experiments as well (e.g. Super-K, K2K, MINOS)

Understanding the detector

- Optical properties of the detector:
  - Dedicated off-situ measurements for measuring light production
  - Laser flask system measures light propagation and absorption in the detector
- Single PMT response:
  - Laser flask system measures the PMT charge and time response
- Track reconstruction:
  - Muon tracker plus scintillator cubes provide tracks with known direction, pathlength, vertex
- Energy scale and resolution:
  - Electron sample with known energy distribution from cosmic muons stopping in the detector

Timing distribution for laser events

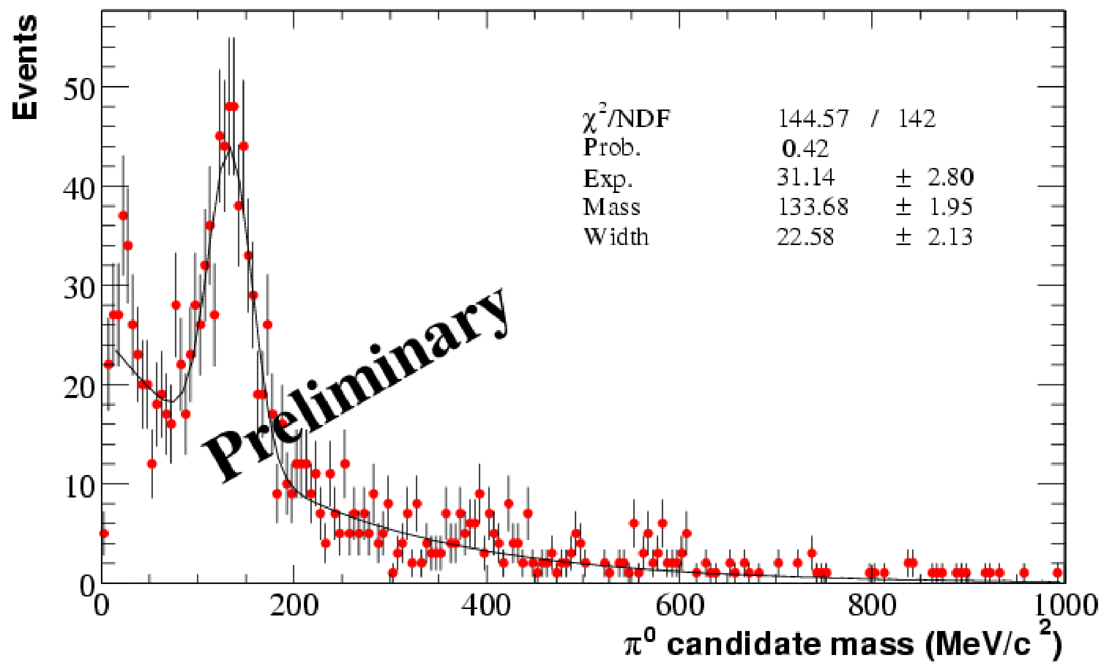




Understanding the reconstruction, particle ID, event selection

- Build on the experience of previous Cherenkov detectors
- Extra handle of scintillation light
- Background to $\nu_\mu \longrightarrow \nu_e$ search: muons or π^0's misidentified as electrons
- Goal: electron events selection with rejection at the level of 10^3 for muons, 10^2 for π^0's

- Invariant mass from relatively pure π^0 data sample is as expected:



Summary

- Many accomplishments in first nine months of data taking
- Proton rate delivered by Booster has dramatically improved over time
- Further Booster upgrades are in the works to reach intended rate
- Detector works beautifully!
- Collected 100,000 neutrino event candidates so far
- Next step is to present in the fall:
  1. first physics results on ν_μ disappearance and cross-sections
  2. updated $\nu_\mu \longrightarrow \nu_e$ sensitivity
- Results on $\nu_\mu \longrightarrow \nu_e$ search to be expected in early 2005

Extra-slides

- MiniBooNE trigger
- $\nu_\mu \longrightarrow \nu_e$ analysis
- $\nu_\mu \longrightarrow \nu_{\cancel{\mu}}$ analysis

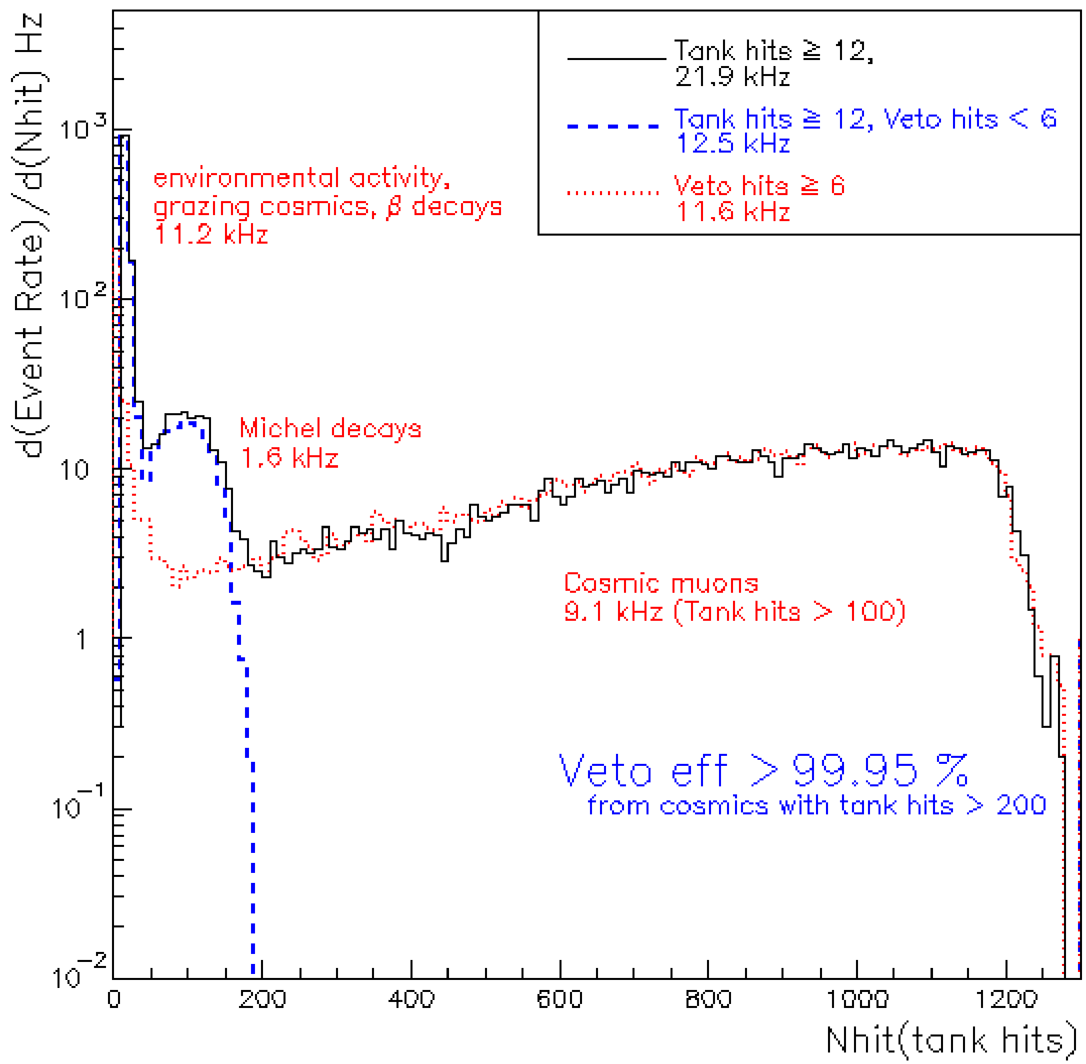
MiniBooNE Trigger

- Typical trigger rates:

Trigger Type	Rate (Hz)
Beam	(currently) 3
Random	2
Laser flasks	1
Tank/Veto NHIT	1
Michel	1
Tracker/Cubes	1
Gamma/Beta	1
Supernova	11
Total	22

- Detector response understood down to a few MeV

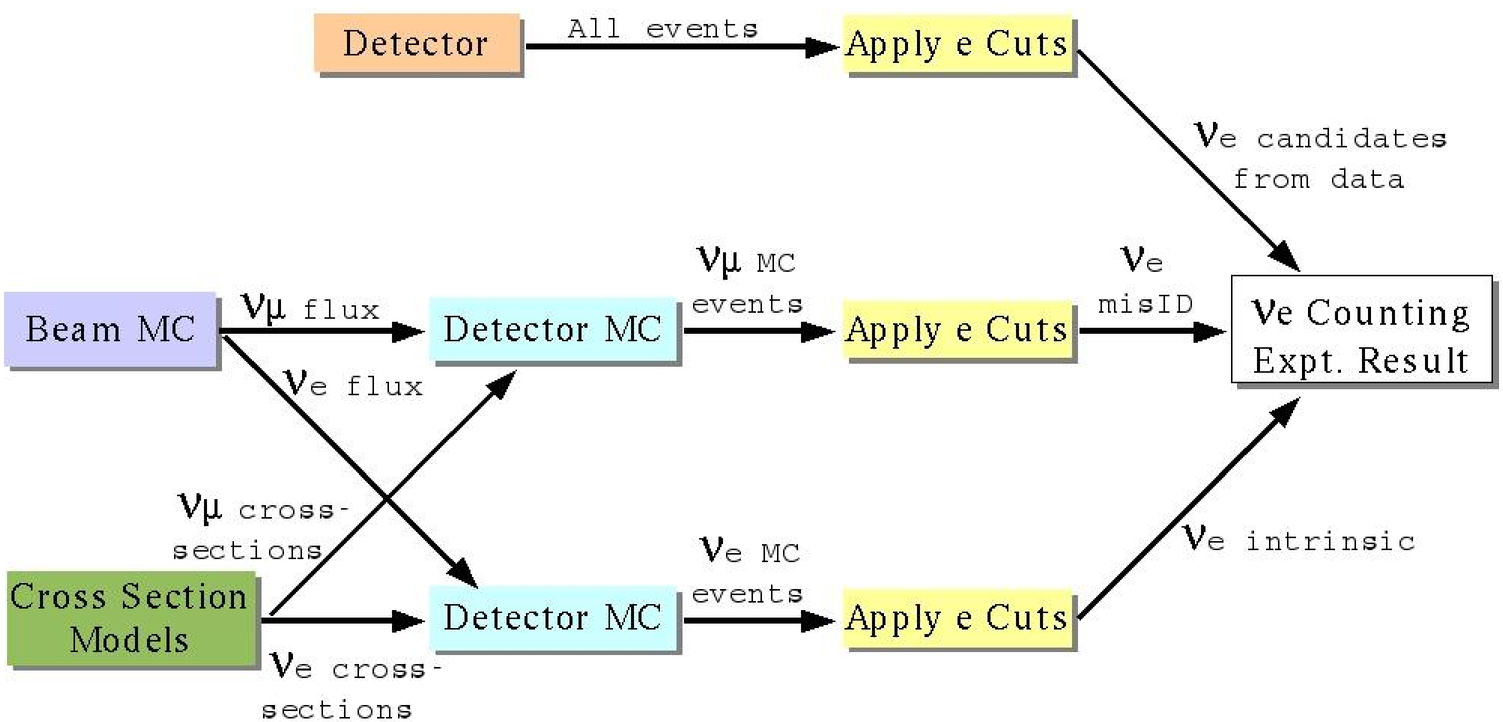
- High veto efficiency



(go back)

$\nu_\mu \to \nu_e$ analysis scheme

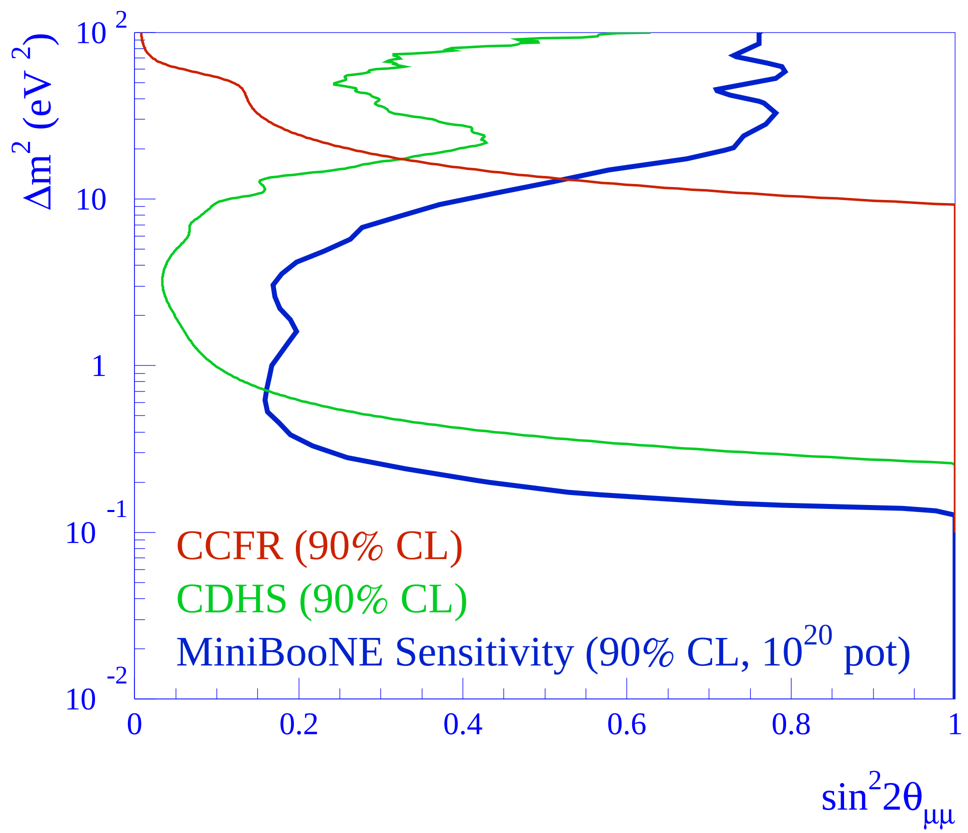
- Ongoing efforts on all fronts needed for the analysis:
  - Neutrino fluxes
  - Neutrino cross-sections
  - Detector calibration
  - Particle ID, event selection algorithms



(go back)

ν_μ disappearance analysis

- Compare predicted visible energy spectrum of ν_μ quasi-elastic events with data
  - search for a ν_μ disappearance signal
- Uncertainties in the flux and cross-section normalization are large
  - sensitivity comes from the energy distribution



(go back)